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Impact of Upgrading Equipment for Strength of Materials Labs on Student Perceptions, Motivation, and Learning

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Abstract

An important component of teaching introductory Strength of Materials (Mechanics of Materials) concepts to undergraduate engineering and technology students is the inclusion of laboratory experiments, which give the students the opportunity to conduct tests and collect data on the materials to obtain relevant properties. These laboratory experiments also allow students to observe firsthand the behavior of materials under different loading conditions, thereby giving them a greater physical feel for these different behaviors. The equipment used to perform small-scale, desktop experiments can range from simple set-ups constructed using every day materials available at a local hardware store to more sophisticated and expensive apparatus manufactured by companies specializing in educational lab equipment. One question of interest to faculty when faced with the decision of selecting the apparatus to be used for these small-scale experiments is whether student perceptions, motivation, and learning in the course are affected by the sophistication and quality of the equipment used to conduct the experiments.

The purpose of this study is to collect and evaluate data to determine if using more sophisticated, higher quality experimental equipment results in improved student outlooks and learning compared to using simple set-ups constructed from every day materials purchased at a hardware store. Data collected include student feedback obtained from short, written surveys about the effectiveness of the laboratories performed with higher quality desktop equipment. The usefulness of the higher end set-ups for improving student understanding of key concepts is evaluated by analyzing student performance on related examination questions and other course components for a cohort who used more expensive apparatus versus a cohort from the previous year who used simple experimental set-ups. In addition, the impact of the laboratory equipment quality and sophistication on student perceptions and motivation for the overall course is studied by looking at course rating information obtained from these two cohorts. Perceptions of the lab instructors on the advantages and disadvantages of using the more expensive versus less expensive experimental set-ups are also presented. The results of this study provide insights on whether upgrading equipment for Strength of Materials labs helps improve the educational experience of students for the overall course and whether those benefits appear to justify the costs of making such upgrades.

Background and Purpose of Study

Over the years it has been generally deemed important to provide undergraduate students in engineering and technology programs with the opportunity to perform laboratory experiments related to key concepts that they learn in the lecture portion of courses. The laboratories are thought to reinforce key concepts and perhaps improve student learning in terms of application and retention of those concepts.

Several researchers have looked at the impact of laboratory experiments for engineering and technology courses on student perceptions, and in some cases student learning, for those courses.

Campbell et al.[1] implemented the use of some simple experiments using low cost materials and toys to teach concepts for dynamic systems. They reported that students found these simple experiments to be very effective or effective for helping them understand dynamic concepts, but no specific data were collected in terms of performance on homework or exams to quantify improvements in learning. Cimbala et al.[2] investigated the impact of a take-home pump performance experiment on student understanding of this topic. They found significant gains in student learning resulting from the use of the experiments and students indicated they liked the hands-on approach.

Strength of Materials (Solid Mechanics or Mechanics of Materials) is a particular course where laboratory experiments have been used to help reinforce key concepts relating to the behavior of materials under applied loads, although the use of such labs as part of the course is not universal. Wadzuk et al.[3] reported that only 29% of civil engineering programs they surveyed indicated that their program requires a laboratory component for Strength of Materials. There are a few studies in the literature concerning the use of laboratories for Strength of Materials in undergraduate engineering and technology programs where survey data have been collected from students about the effectiveness of the labs. Bhargava et al.[4] used both virtual labs, consisting of high quality video and audio of a lab test, and hands-on physical labs for undergraduate Statics and Strength of Materials courses. Results of their study indicate that students preferred the physical labs due to the hands-on experience, having people available to answer questions, and not having to stare at a computer screen. Douglas and Holdhusen[5] and Denton[6] both had their students perform simple strength of materials experiments using common materials available at a hardware store. Douglas and Holdhusen[5] had on-line students who did the simple experiments at home. They reported that overall the student response to the experiments was positive and the students stated that the labs helped to reinforce concepts from on-line lectures. Denton[6], who had on-campus students perform simple experiments, reported that 60% to 83% of the students found the experiments to be helpful or very helpful. In all of these studies little to no data were collected and/or reported on whether the use of the experiments produced a change in student performance by looking at exam or other performance measuring data. Denton[6] did indicate a 15% improvement in exam results for students' abilities to recognize single versus double shear, which was a focus of one of their labs.

One important question that can arise when planning laboratories for Strength of Materials is whether the sophistication and quality of the equipment used for experiments have any impact on student perceptions of and motivation for the course, as well as the learning and performance of the students. There were no apparent studies found in the literature that evaluate this issue. The purpose of the study described in this paper is to determine whether using more sophisticated, higher quality desktop experimental equipment results in improved student outlooks and learning in Strength of Materials compared to using simple, homemade set-ups constructed from every day materials purchased at a hardware store. The results of this study should provide insights on whether upgrading equipment for Strength of Materials labs helps improve the educational experience and learning of students for the overall course and whether those benefits appear to justify the costs of making such upgrades.

Details of Study

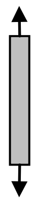
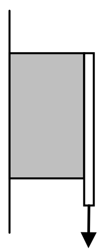
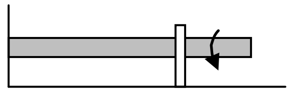
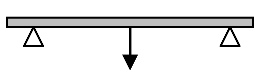
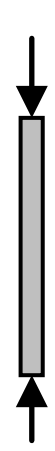
The current study investigating the impacts of using more sophisticated, higher quality equipment in undergraduate Strength of Materials laboratories on the perceptions, motivation, and learning of students in the overall course was conducted by the authors using the two sections of the Strength of Materials course they taught in Fall 2013 and Fall 2014 in the civil engineering technology program at Rochester Institute of Technology. This 15-week-long course is typically taken in the second year of the five-year-long undergraduate civil engineering technology program and consists of three hours of lecture and two hours of recitation per week. Each author taught their own course section in Fall 2013 and Fall 2014, with each course section having anywhere from 26 to 31 students enrolled. Four strength of materials experiments were used in the 2013 course sections and these experiments were performed using simple, homemade desktop set-ups constructed from materials purchased at a local hardware store. In 2014 the same experiments were performed in the course sections, with the exception that the experimental set-ups were more sophisticated, higher quality desktop equipment purchased from educational equipment manufacturers. In addition, one new experiment was added in 2014. A list of the experiments performed included:

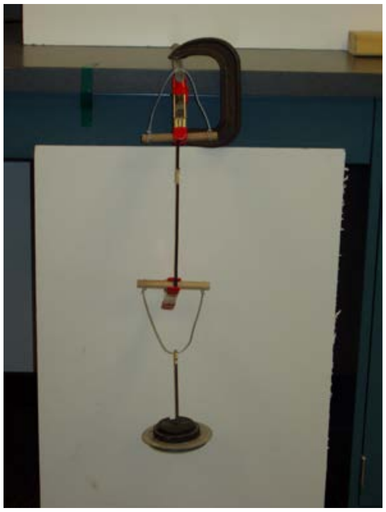
- Tension testing of a slender member,
- Shear deformation of a sponge block,
- Torsion testing of a long rod,
- Deflection of a simply supported beam, and
- Buckling of small-scale columns (only used in 2014).

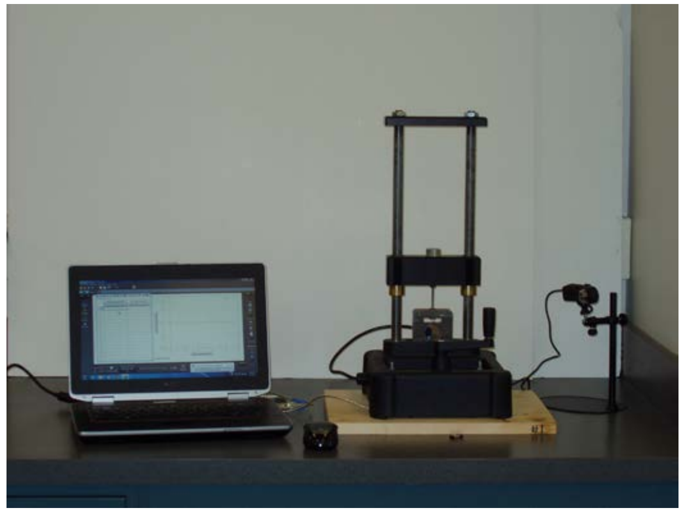
Table 1 presents information regarding the basic set-up and process used for each experiment, as well as highlights some of the differences between how these experiments were performed in 2013 versus 2014. The shear deformation of a sponge block was the only experiment where the exact same equipment (homemade from hardware store materials) and procedure were used in both 2013 and 2014. For all of the other experiments the equipment used in 2014 was purchased from educational equipment manufacturers. Figures 1 and 2 show photographs of both the homemade and manufactured tensile testing equipment and the homemade and manufactured torsion testing equipment, respectively.

The construction details for the homemade equipment used for the labs in 2013 came directly from the paper by Douglas and Holdhusen[5], as well as additional information provided by Dr. Jamie Douglas to the authors in summer 2013. The manufactured tensile testing equipment used in 2014 was purchased from Pasco of Roseville, CA, and the manufactured equipment for torsion, beam deflection, and column buckling was purchased from USDidactic (U.S. representative of the German manufacturer Gunt). Four to five units of each homemade experimental setup were constructed with a total cost of about $400 for the materials and student labor to produce all of the experiments. The purchase of four units each of the more sophisticated tension testing, torsion testing, beam deflection, and column buckling equipment (note: torsion testing and beam deflection experiments used the same piece of equipment) from the manufacturers cost a total of about $43,000.

Table 1 - Strength of Materials Laboratory Experiments

Experiment & Side View	Process	Differences: 2013 vs. 2014
1. Tension test of slender member 	• Apply increments of axial load and measure axial deformation. • Calculate stress and strain for each load increment. • Plot axial stress-strain curve and determine modulus of elasticity, E.	2013: Use plastic tube for member, apply force with weights, measure displacements with ruler, do manual calcs/plots. 2014: Use “small” metal rods in hand cranked testing machine, force & deformation data collected electronically, calcs/plots done automatically, samples loaded to failure.
2. Shear deformation of block 	• Apply increments of shear force and measure shear deformation. • Calculate shear stress-strain for each load increment. • Plot shear stress-strain curve and determine shear modulus, G.	2013: Use section of sponge for block, apply force with weights, measure displacements with ruler, do manual calcs/plots. 2014: Same as 2013.
3. Torsion testing of long rod 	• Apply increments of torque and measure angular displacement/twist of rod. • Back-calculate the shear modulus, G, for each load increment using formula: $\phi = (TL)/(JG)$	2013: Use wooden dowel, apply torque by hanging weights off-center, measure angle of twist using marks on paper target and a protractor. 2014: Similar to 2013 except use two different metal rods, measure angular displacement using dial gauge and convert to an angle.
4. Beam deflection 	• Apply increments of force at center of beam and measure downward deflection of beam. • Back-calculate the modulus of elasticity, E, for each load increment using: $y = (PL^3)/(48EI)$	2013: Use wood and steel beams, apply force by hanging weights, measure deflection using dial gauge. 2014: Similar to 2013 except use aluminum and steel beams.
5. Column buckling 	• Apply increments of vertical compressive force until column buckles. • Calculate theoretical force for buckling using Euler’s equation. • Compare measured vs. theoretical forces.	2013: Not available. 2014: Use column consisting of spring steel having narrow rectangular cross-section; experiment repeated for four different end support conditions.

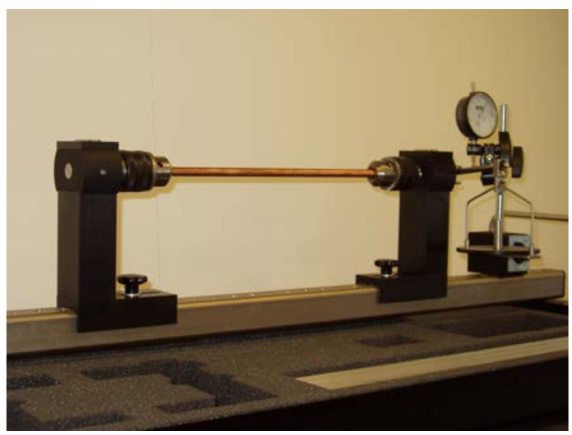




Homemade

From Equipment Manufacturer

Figure 1 – Tension Testing Equipment



Homemade

From Equipment Manufacturer

Figure 2 – Torsion Testing Equipment

Each laboratory experiment performed in 2013 and 2014 was typically completed by groups consisting of 3 to 5 students in 50 to 60 minutes during a two-hour recitation period. Prior to completing an experiment, students were exposed to the related theoretical concepts through previous lectures and a completed homework assignment. Once a group collected the relevant data for an experiment by following the step-by-step instructions provided, they then reduced that data and answered some straightforward follow-up questions related to that lab on an individual basis either in class or, if there was not sufficient time, outside of class.

Other than the differences in the lab equipment used, the teaching methods and materials used for students in the 2013 and 2014 Strength of Materials course cohorts were essentially the same. Both cohorts completed a total of fourteen weekly homework assignments, four 60-minute-long examinations, and one two-hour-long comprehensive final examination in addition to the labs performed during the semester. One slight difference in instruction methods for students in 2013 versus 2014 was the students in the 2013 cohort completed the pre-requisite Statics course through the Mechanical Engineering Technology Department whereas students in the 2014 cohort were taught by faculty in the civil engineering technology program (same civil engineering technology faculty who then taught Strength of Materials).

As mentioned earlier, each of the authors taught a section of Strength of Materials in 2013 and again in 2014. When looking at data from this study, course sections taught by the different instructors will typically be kept separate from each other. Students taught by Author/Instructor 1 in 2013 and 2014 will be referred to as Control Group 1 and Experimental Group 1, respectively, and students taught by Author/Instructor 2 will be referred to as Control Group 2 and Experimental Group 2, respectively. This approach should provide two separate sets of data for assessing the impacts of the higher quality equipment. In both cases the term "Experimental Group" refers to students in 2014 who used the more sophisticated, higher quality lab equipment and "Control Group" refers to students in 2013 who used the homemade lab equipment.

Data on the impacts of using more sophisticated, higher quality lab equipment on the perceptions and performance of students in Strength of Materials were obtained in a number of different ways. Student feedback from the experimental groups who used the more sophisticated lab equipment in 2014 was obtained to see if they felt the labs performed during the semester helped them to better understand the topics related to each of the labs, as well as whether they would recommend using the lab again in the future. This feedback was obtained by having the students complete a simple seven or eight question survey at the end of each lab. Changes in student perceptions and motivation for the Strength of Materials course due to using the higher quality equipment was obtained by making use of the feedback given on the standard course evaluations (SmartEvals) completed by enrolled students at the end of a course, as well as reviewing student performance on homework and labs compared to the prior year. Lastly, the impact of using the more sophisticated equipment on improving student learning, if any, was inferred by comparing student performance on specific examination questions related to the topics of the experiments, as well as looking at changes in overall scores on examinations and the course.

Although it would have been interesting to collect survey information about the usefulness of the simple, homemade experiments from the control groups in 2013 and compare it with the survey data from the experimental groups who used the more sophisticated experiments in 2014, such information was not collected because this study was not anticipated in 2013. However, the instructors' perceptions of the reactions of the control groups to the homemade experiments are provided in this paper. In addition, survey data were collected from the experimental groups about the shear deformation of the sponge block experiment and this exact same experiment was used by the control groups in 2013. Therefore some information was collected about one of the homemade experiments.

When checking to see if there was an improvement in the performance of an experimental group (used the higher quality equipment in 2014) relative to a control group (used the homemade equipment in 2013), a statistical evaluation was conducted. The Ryan-Joiner goodness-of-fit test was used to check the plausibility of assuming a normal distribution for the performance data (exam, homework, or lab scores) for each group. If the data for each group fit a normal distribution, a one-sided t-test was performed using the null hypothesis that the difference between the mean scores of the two groups equals zero (experimental and control group mean scores are the same) at the usual $\alpha = 0.05$ significance level (or 95% confidence level). A computed p value greater than 0.05 caused the null hypothesis to be accepted whereas a p value of less than 0.05 caused the null hypothesis to be rejected in favor of the alternative hypothesis that the difference between the mean scores is negative (experimental group mean score is higher than the control group mean score). For cases where the performance data did not fit a normal distribution, a one-sided Mann-Whitney test was performed using the null hypothesis that the difference between the median scores equals zero (experimental and control group median scores are the same) at the usual $\alpha = 0.05$ significance level (or 95% confidence level). A computed p value greater than 0.05 caused the null hypothesis to be accepted whereas a p value less than 0.05 caused the null hypothesis to be rejected in favor of the alternative hypothesis that the difference between the median scores is negative (experimental group median score is higher than the control group median score).

A comparison of the cumulative grade point averages (GPA) of the students in the experimental and control groups at the time they entered the Strength of Materials course was performed. The twenty seven students in Control Group 1 had a mean GPA of 3.24 and the twenty five in Experimental Group 1 had a mean of 3.05. A two-tailed t-test performed between these mean grade point averages gave $t = 1.47$ and $p = 0.148$ (for 52 degrees of freedom) indicating no significant difference. The twenty students in Control Group 2 had a mean GPA of 3.02 and the twenty five in Experimental Group 2 had one of 3.05. A two tailed t-test performed between these mean grade point averages gave $t = -0.23$ and $p = 0.828$ (for 29 degrees of freedom) indicating no significant difference. These results imply that the experimental and control groups entered the Strength of Materials course with similar abilities.

Presented below are the findings of this study in regards to the impact of more sophisticated, higher quality desktop laboratory equipment on the perceptions, motivations, and learning of students in a Strength of Materials course, as well as their feedback about using the higher quality equipment. The authors' insights, as instructors, on the potential benefits of using the more sophisticated equipment are also given, along with their views on how those benefits compare to the higher cost for purchasing this equipment.

Student Feedback on 2014 Labs

Subjective, quantitative feedback from students in the 2014 experimental groups that used the more sophisticated, higher quality lab equipment was obtained by having the students complete a survey (separate survey for each lab) where they responded to seven or eight statements about each laboratory they performed. The overall purpose of the surveys was to get a sense as to whether the labs were interesting, helped students to better understand certain concepts and related calculations, and used equipment that was adequate. Students responded to the survey statements using responses (equivalent five-point Likert scale rating given in parentheses) of either strongly disagree (= 1), disagree (= 2), neutral (= 3), agree (= 4), or strongly agree (= 5). In addition, space was provided at the bottom of each survey where students could provide written comments regarding things they liked about each demonstration and things they disliked or thought could be improved. Given the similarity of the responses received from Experimental Group 1 (taught by Instructor 1 in 2014) and Experimental Group 2 (taught by Instructor 2 in 2014), the survey data for the two groups are combined and presented together.

Table 2 presents the survey statements used for getting student feedback for the tensile testing lab (performed with a tensile testing machine), as well as the response data from students. For each statement, the number and corresponding percentage of students (out of the forty-five

Table 2 – Survey Results for Tensile Testing of Slender Members

Survey Statement	Number and Percentage of Students Selecting Likert Rating 1 – 5*					Mean Rating
	1	2	3	4	5	
1. I found this laboratory to be interesting.	0 0.0%	0 0.0%	2 4.4%	34 75.6%	9 20.0%	4.16
2. Performing tensile tests on different materials helped me understand difference between ductile and brittle behavior.	0 0.0%	1 2.2%	4 8.9%	29 64.4%	11 24.4%	4.11
3. Plotting of stress-strain curve by software during tensile test helped me to better understand stress-strain behavior.	0 0.0%	2 4.4%	12 26.7%	28 62.2%	3 6.7%	3.71
4. Looking at failed specimens after tensile tests helped me to see physical difference between ductile and brittle failure.	0 0.0%	1 2.2%	8 17.8%	23 51.1%	13 28.9%	4.07
5. It would be more helpful for me if we had to make measurements and reduce data manually.	3 6.7%	18 40%	16 36.5%	7 15.6%	1 2.2%	2.67
6. The written instructions for completing this laboratory were clear and easy to follow.	0 0.0%	1 2.2%	5 11.1%	26 57.8%	13 28.9%	4.13
7. I would not recommend that this lab be used again when teaching Strength of Materials.	17 37.8%	19 42.2%	7 15.6%	1 2.2%	1 2.2%	1.89

*Note: In rating system 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

students who completed the survey) who selected a particular Likert response are shown. In addition, the mean Likert scale rating obtained for each statement is provided in the last column. The mean Likert rating of 4.16 for statement 1, along with the fact that 95% of the students agree or strongly agree with this statement, provides a strong indication that students found the tensile testing experiment interesting. The mean ratings of 4.11 and 4.07 for statements 2 and 4, along with the fact that 80% to 90% of the students agree or strongly agree with these statements, indicates that they found the testing of different materials to failure helpful for their understanding of ductile versus brittle behavior. Based on the response of 3.71 for statement 3 and 2.67 for statement 5, it appears that the automatic data collection and plotting of the stress-strain curve by the testing software helped students better understand stress-strain behavior and the students did not feel it would be more beneficial for them to do the measurements and plotting manually. Since only a small minority (4%) of the students agree or strongly agree with statement 7 that the tensile testing lab should not be used again, it can be inferred that most students found the lab useful.

Student survey responses for the other four lab experiments (shear testing, torsion testing, beam deflection, and column buckling) are summarized in Table 3. The number of respondents who completed a survey for each of the four experiments ranged from 39 to 49. Given the similarity of the survey statements used to obtain student feedback for these four labs, and the similarity of the responses received, mean ratings were calculated for each survey question based on all four experiments. These mean ratings include the mean percentage of respondents who selected

Table 3 – Mean and Range of Responses to Survey Questions for Four Labs Combined (includes Shear Testing, Torsion Testing, Beam Deflection, Column Buckling)

Survey Statement	Mean Percentage of Students Selecting Likert Rating 1 – 5*					Mean Likert Rating	
	1	2	3	4	5	Overall Mean	Range
1. I found this laboratory to be interesting.	0.0	1.0	13.2	63.0	22.8	4.08	3.92 - 4.34
2. Performing the tests helped me better understand the associated concept.	0.0	4.0	10.6	56.4	29.0	4.10	3.87 - 4.30
3. Measurements and calculations performed in this lab increased my ability to perform computations related to this concept.	0.0	3.0	15.4	56.3	25.3	4.04	3.92 - 4.23
4. Experimental set-up used for observing and measuring the behavior was adequate.	0.0	0.6	13.8	68.3	17.3	4.02	3.93 - 4.28
5. It would be more helpful for me if measurements were done electronically and calculations done automatically by software.	14.4	34.7	31.0	12.2	7.7	2.64	2.39 - 2.76
6. The written instructions for completing this laboratory were clear and easy to follow.	0.0	0.0	14.4	60.7	24.9	4.10	3.98 - 4.19
7. I would not recommend that this lab be used again when teaching Strength of Materials.	31.1	47.8	12.2	7.1	1.70	2.00	1.89 - 2.12

*Note: In rating system 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

particular Likert responses to a statement (obtained by averaging the percentage of students who selected that response for that particular statement for all four labs) and the overall mean Likert rating for that statement (obtained by averaging the mean Likert rating for that statement for all four labs). The range of the mean Likert ratings for a statement is also provided based on all four labs.

The mean Likert rating of 4.08 for statement 1 in Table 3, along with the fact that 86% of the students agree or strongly agree with this statement, provides a strong indication that students found the four labs (shear testing, torsion testing, beam deflection, and column buckling) interesting. The mean ratings of 4.10 and 4.04 for statements 2 and 3, along with the fact that 80% to 85% of the students agree or strongly agree with these statements, indicates that the four experiments helped them to better understand the theoretical concepts associated with the labs and increased their ability to perform computations related to those concepts. Based on the mean Likert responses of 4.02 and 4.10 for statements 4 and 6, respectively, and the fact that 85% of students agreed or strongly agreed with these statements, it appears the experimental set-ups and lab instructions were satisfactory. The mean response of 2.64 for statement 5 indicates that more automation of measurements and data reduction was not needed. Since only a small minority (9%) of the students agreed or strongly agreed that the four labs should not be used again (statement 7), it can be inferred that most students found the labs useful.

There were some unique statements and responses associated with the surveys for the shear testing and column buckling labs that do not appear in Table 3 and need to be highlighted. For the shear testing of the sponge block lab (only lab performed in 2014 using homemade equipment) the mean Likert response was 3.59 to a statement that plotting of the shear stress-strain curve helped better the students' understanding of the shear stress-strain behavior of a material. This response seems to indicate that plotting of the shear stress-strain curve was only of moderate value to the students. For the column buckling experiment a mean response of 4.27 was obtained for the statement that the visual observations and measurements made in that lab helped better the students' understanding of the end condition effects on the deformed shape and buckling load for a column. It appears that the column buckling experiment gave students a better understanding of how the end conditions of the column affect buckling.

Over one hundred written comments were provided by students on the surveys concerning things they liked about the five different labs. An overview of those remarks is presented here. Several students appreciated the hands-on and visual nature of the labs, and they mentioned that the labs helped them to better understand the related concepts. Students also noted that the labs were typically quick, easy, and well organized. There were several comments about the cool and professional appearance of the equipment purchased from educational equipment manufacturers. One student liked the fact that they were not given the formulae needed to reduce the lab data and they had to figure that out themselves. Some comments (about thirty) were provided by students concerning things they thought could be improved or didn't like in the labs. Some students mentioned it would have been helpful if they had more time to conduct the experiments. Several noted it would be helpful if they could test a greater variety of materials. A few noted that, at times, setting up the equipment was tedious and in some cases the equipment seemed sensitive. One student thought some labs would go smoother if the equipment was fully set-up beforehand and two students thought it would be helpful if more measurements were made with electronic devices.

Overall, the response to the survey questions and the written responses that students provided indicate that the five labs used in 2014 were worthwhile and beneficial. It should be noted that the response of the students to survey statements concerning the effectiveness of the shear deformation experiment, which used homemade equipment, was more or less the same as their responses to statements for the other four experiments that used the more sophisticated equipment purchased from educational equipment manufacturers.

Student Perceptions of Course

No data or feedback were collected in this study that directly address whether the use of the more sophisticated, higher quality laboratory equipment improved student perceptions of the Strength of Materials course. However, information from the seven statements on the standard course evaluations (SmartEvals) completed by students at the end of a semester may indirectly provide insight into this issue. The statements to which students respond are given below:

1. The instructor enhanced my interest in this subject.
2. The instructor presented the course material in an organized manner.
3. The instructor communicated the course material clearly.
4. The instructor established a positive learning environment.
5. The instructor provided helpful feedback about my work in this course.
6. The instructor supported my progress towards achieving the course objectives.
7. Overall, this instructor was an effective teacher.

Students respond to each of these statements using responses (equivalent five-point Likert scale rating given in parentheses) of either strongly disagree (= 1), disagree (= 2), neutral (= 3), agree (= 4), or strongly agree (= 5).

Table 4 provides a summary of student ratings received by the instructors for each of the seven statements in 2013 and 2014, along with an average rating for all seven statements. As seen from the table, the ratings of both instructors go up somewhat from 2013 to 2014 for nearly all of the statements. In addition, the overall average for each instructor goes up. These results indicate that there was some improved student perceptions of both instructors and perhaps the course. It is possible that part of this improved perception might be the result of the improved lab equipment used by the experimental groups versus the homemade lab experiments used by the control groups, since this was the only real significant change made in the course between 2013 and 2014. However, it is important to note that there could also be other factors involved in the improved ratings given that Instructor 2 had similar improvements in his ratings from 2013 to 2014 for two other courses that he taught (one course had an increase in the average rating from 4.1 to 4.4 and the other an increase from 4.2 to 4.4) and there were no significant changes made in those courses. It should be noted that 2013 and 2014 were the only years that Instructors 1 and 2 taught the one-semester-long Strength of Materials class. Prior to 2013, when Rochester

Table 4 – Student Rating of Instructors

Survey Statement The course instructor:	Instructor 1[1]		Instructor 2[2]	
	2013	**2014**	**2013**	**2014**
1. enhanced my interest in this subject.	3.9	4.3	4.2	4.2
2. presented material in organized manner.	4.5	4.6	4.5	4.6
3. communicated the course material clearly.	4.0	4.5	4.3	4.6
4. established positive learning environment.	4.2	4.7	4.4	4.6
5. provided helpful feedback about my work.	4.3	4.6	4.2	4.4
6. supported my progress towards achieving objectives.	4.3	4.7	4.4	4.6
7. was an effective teacher.	4.2	4.8	4.4	4.5
Average rating:	**4.2**	**4.6**	**4.3**	**4.5**

Notes: 1. Survey completion rate of 24 out of 31 in 2013 and 22 out of 26 in 2014. 2. Survey response rate of 19 out of 26 in 2013 and 12 out of 27 in 2014.

Institute of Technology operated under the quarter system, both instructors taught an advanced Strength of Materials course to third year students who had taken the first Strength of Materials course in their second year through the Mechanical Engineering Technology Department. For that reason, instructor rating data prior to 2013 would not be directly comparable to 2013 and 2014 and therefore are not presented.

Student Motivation

In the one semester Strength of Materials course, students completed fourteen weekly homework assignments that reinforced concepts learned in lecture each week. Although a lab relating to a particular topic was performed after the lecture material and associated homework were completed, consistent improvements in homework performance between the control and experimental groups in 2013 and 2014 could potentially be associated with increased student motivation in the course generated by the use of higher quality, more sophisticated lab equipment. Likewise, improvements in the lab assignment scores may indicate improved student motivation caused by the higher quality equipment.

Homework

A plot of the weekly median homework scores for Experimental Group 1 in 2014 and Control Group 1 in 2013 is presented in Figure 3 and the same type of data are presented for Experimental Group 2 and Control Group 2 in Figure 4. Median scores are presented and used

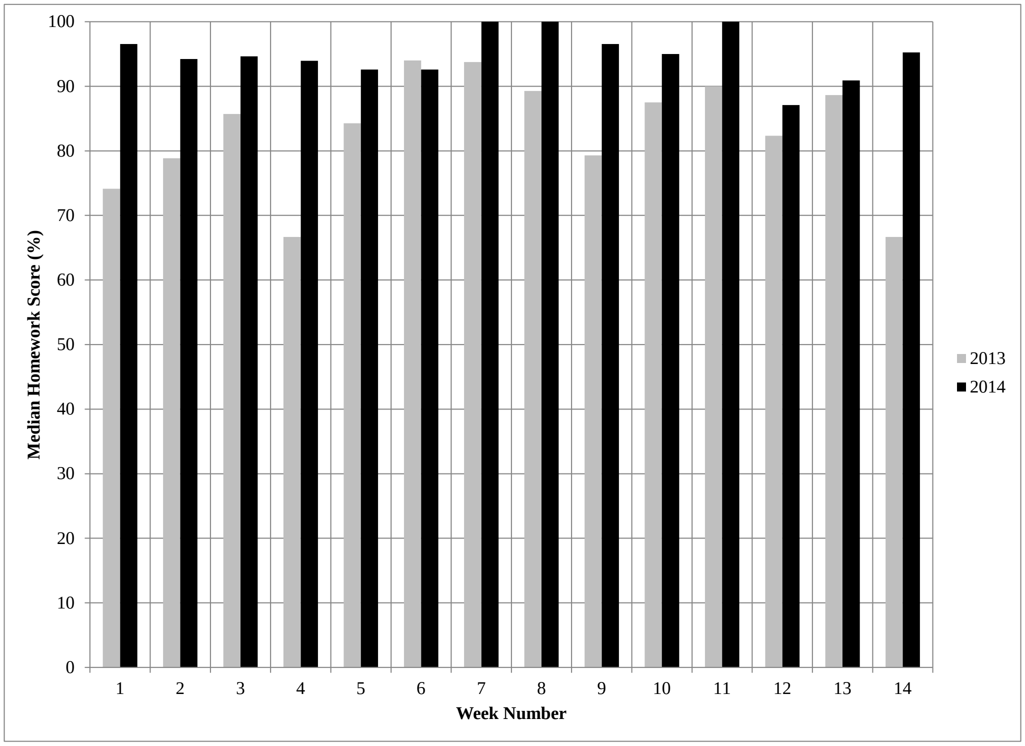


Figure 3 – Weekly Median Homework Scores for Experimental & Control Groups 1

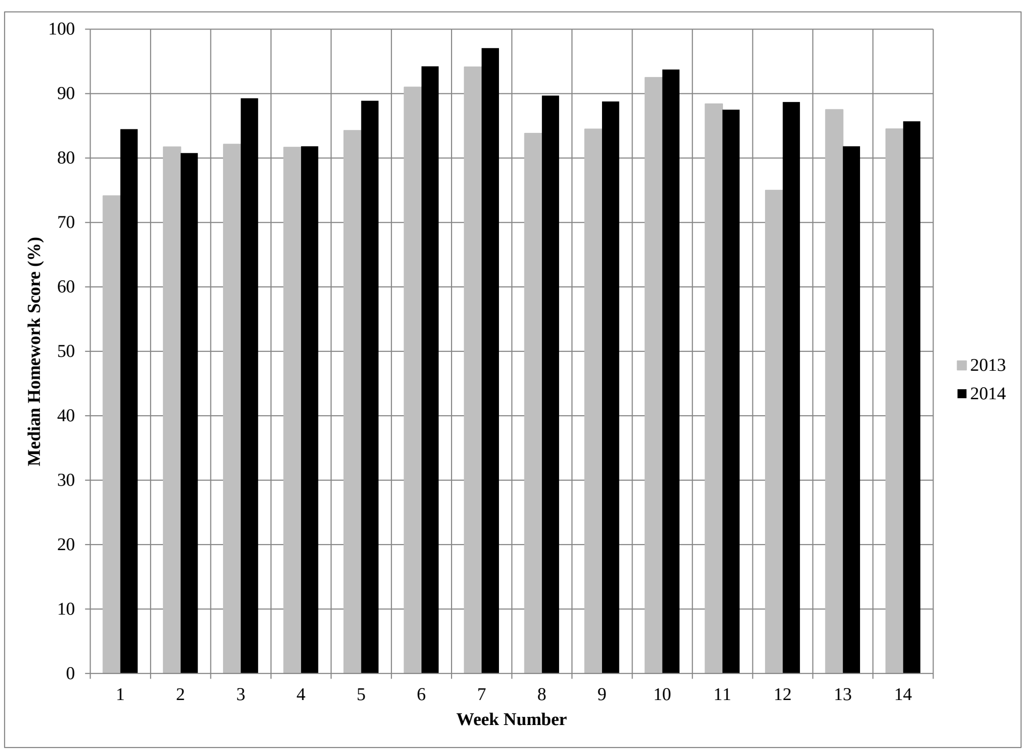


Figure 4 – Weekly Median Homework Scores for Experimental & Control Groups 2

instead of mean scores because most of the homework data did not fit a normal distribution. However, the trends seen in the mean scores were similar to the median scores.

As seen in Figure 3, the median homework scores of Experimental Group 1were numerically higher compared to Control Group 1 in 13 of the 14 weeks. Mann-Whitney tests performed between the scores of the two groups for each of those 13 homework assignments indicate the median scores of Experimental Group 1 are statistically higher than Control Group 1 for 12 of those 13 assignments. The median homework scores of Experimental Group 2 are numerically higher than Control Group 2 for 10 of the 14 weeks, as shown in Figure 4, but the Experimental Group median for only one of those 10 assignments is statistically higher.

The homework data do not appear to consistently support the idea that use of the higher quality lab equipment in 2014 produced higher student motivation for the Strength of Materials course, thereby resulting in consistent improvement in homework scores for all students. The statistically higher median scores of Experimental Group 1 compared to Control Group 1 could suggest some impact of the higher quality equipment on the motivation of students. However, the better homework performance of Experimental Group 1 compared to Control Group 1 could be partially caused by the different student graders used for the two groups. For Experimental Group 2 and Control Group 2, where the same instructor served as the grader, there was no substantial difference in the homework performance of the two groups.

Laboratories

As previously explained, the control and experimental groups performed experiments related to tension testing, shear deformation, torsion testing, and beam deflection (see Table 1 for experiment details) during the semester in 2013 and 2014, respectively. In addition, the experimental groups also performed a column buckling experiment. As part of the lab exercises, both groups completed laboratory assignment sheets that involved computations, plotting of graphs (when needed), and evaluation of the results associated with the lab.

The mean and median lab scores of Control Group 2 and Experimental Group 2 are given in Table 5, along with values that assess the statistical significance of any improvement from 2013 to 2014. As seen from the table, the mean and median scores for both groups are mostly in the middle 90's. The only exception is Experimental Group 2 scored in the middle 80's for the tension test and Control Group 2 scored in the high 80's for the beam deflection lab. There was no improvement in the lab scores from 2013 to 2014, with the exception of the beam deflection lab where the median score of Experimental Group 2 was statistically higher than Control Group 2. Complete lab score data were not available for Control Group 1 and Experimental Group 1.

Overall, the lab scores for the control and experimental groups do not support the idea that the higher quality lab equipment used in 2014 increased student motivation.

Student Learning

The impact of using the more sophisticated, higher quality lab equipment on the learning of students, if any, was inferred by comparing the performance of the experimental and control

Table 5 – Performance of Group 2 on Laboratory Assignments

Laboratory Experiment	Mean │ Median Score on Lab (%)		Statistical Values[1,2]
	2013 (Control)	2014 (Experimental)	
Tension test of slender member	96.2 │ 95.8	84.2 │ 86.8	NI
Shear deformation of block	96.2 │ 95.8	95.7 │ 95.8	NI
Torsion testing of long rod	97.3 │ 95.8	96.8 │ 97.1	NI
Beam deflection	88.6 │ 89.5	97.2 │ 97.2	$W = 317.5$ $p = 0.000$
Column buckling	NA[3]	98.7 │ 100.0	-

Notes: 1. NI means there was no improvement in scores from 2013 to 2014 and therefore a statistical analysis was not performed. 2. W is statistical value from Mann-Whitney test based on medians. p is probability for accepting null hypothesis of no difference between 2013 and 2014 scores. p value < 0.05 signifies the null hypothesis is rejected and the alternative that the 2014 scores are higher is accepted. 3. NA = Not available. Column buckling lab not done in 2013.

groups on specific examination questions related to the topics of some experiments, as well as looking at changes in overall scores on examinations and the course. Since the only difference in course delivery to the two groups was the use of higher quality equipment versus homemade equipment for the lab component, consistent improvement in any of these course indicators could indicate a potential effect of lab equipment quality on student learning.

Specific Exam Questions

In 2013 and 2014 the control and experimental groups in the Strength of Materials course were both given three examination questions that tied to concepts covered in three different laboratory experiments. These three exam problems, which are listed in Table 6, included calculating the:

- angle of twist of a rod subjected to multiple torques,
- deflection of a simply supported beam subjected to multiple loads, and
- buckling load for a column having a non-standard cross-section.

Each of these problems appeared in an exam after the lab related to that topic, as well as the relevant homework, were completed.

Table 6 presents the mean and median scores of Control Group 1 and Experimental Group 1 on the three examination questions (the questions given in 2013 and 2014 were similar to each

Table 6 – Performance of Group 1 on Specific Exam Problems

Problem Type	Mean │ Median Score on Problem (%)		Statistical Values[1,2]
	2013 (Control)	2014 (Experimental)	
Torsion – calculate angle of twist of rod subjected to multiple torques	72.6 │ 72.7	67.2 │ 68.8	NI
Beam Deflection – calculate deflection of simply supported beam subjected to multiple loads	71.1 │ 80.0	85.4 │ 92.9	$W = 719.0$ $p = 0.002$
Column Buckling[3] – calculate buckling load for column having non-standard cross-section	54.3 │ 61.5	57.7 │ 60.0	$t = -0.60$ $p = 0.276$

Notes: 1. NI means there was no improvement in scores from 2013 to 2014 and therefore a statistical analysis was not performed. 2. W is statistical value from Mann-Whitney test based on medians and t is statistical value from Student t test based on means. p is probability for accepting null hypothesis of no difference between 2013 and 2014 scores. p value < 0.05 signifies the null hypothesis is rejected and the alternative that the 2014 scores are higher is accepted. 3. Results for a column buckling problem were also available for Group 2 for both years. Mean scores for Group 2 went down from 57.0 in 2013 to 54.0 in 2014.

other, but not identical), as well as values to evaluate the statistical significance of any improvement in performance from 2013 to 2014. Comparative data for Experimental Group 2 and Control Group 2 were not available for the torque and beam deflection problems because the exam papers for Control Group 2 were not retained (Control Group 2 was allowed to retain their exams in 2013).

As seen from Table 6, scores for Experimental Group 1 were numerically higher than Control Group 1 for the beam deflection and column buckling examination questions. However, based on the computed statistical values only the score on the beam deflection problem was statistically higher for Experimental Group 1. The score of Experimental Group 2 on a column buckling problem did not improve compared to Control Group 2, as explained in a table note. Based on this information, only the higher quality equipment used for the beam deflection experiment might have improved student learning for that topic, as reflected in exam question performance.

Individual Exams

In order to evaluate whether using the more sophisticated, higher quality lab equipment had any indirect impact on overall student learning for the Strength of Materials course, the mean and median scores of the experimental and control groups on the four 60-minute exams and two-hour comprehensive final exam were compared, as shown in Table 7. As seen in this table, the mean and median exam scores of Experimental Group 1 (2014) are higher than those of Control Group 1 (2013) for every examination. However, the statistical values indicate that only the score on exam 3 is statistically higher for Experimental Group 1 compared to Control Group 1. There

Table 7 – Performance on Exams

Exam	Group 1			Group 2		
	Mean │ Median (%)		Statistical Values[2]	Mean │ Median (%)		Statistical Values[1]
	2013	2014		2013	2014	
Exam 1	68.8 │ 66.7	75.5 │ 79.0	W = 796.0 p = 0.050	67.0 │ 71.7	66.2 │ 69.7	NI
Exam 2	81.8 │ 85.0	82.4 │ 87.1	W = 839.5 p = 0.172	76.4 │ 80.0	72.3 │ 75.7	NI
Exam 3	67.6 │ 70.6	77.1 │ 81.0	t = -2.35 p = 0.011	77.7 │ 76.5	73.3 │ 75.6	NI
Exam 4	71.5 │ 72.6	74.3 │ 76.5	t = -0.61 p = 0.271	86.7 │ 88.7	77.8 │ 82.4	NI
Final Exam	69.4 │ 68.4	75.0 │ 75.5	t = -1.21 p = 0.115	73.1 │ 78.8	69.4 │ 69.6	NI

Notes: 1. NI means there was no improvement in scores from 2013 to 2014 and therefore a statistical analysis was not performed. 2. W is statistical value from Mann-Whitney test based on medians and t is statistical value from Student t test based on means. p is probability for accepting null hypothesis of no difference between 2013 and 2014 scores. p value < 0.05 signifies the null hypothesis is rejected and the alternative that the 2014 scores are higher is accepted.

was no improvement in the exam scores of Experimental Group 2 compared to Control Group 2. These data seem to indicate that using the higher quality lab equipment had no significant impact on overall student learning.

Overall Course Grades

The mean course grades for Experimental Group 1 and Control Group 1 were 78.1% and 73.1%, respectively, and the median course grades were 82.1% and 75.4% , respectively. The course grades of Experimental Group 1 and Control Group 1 were not statistically different. The mean course grades for Experimental Group 2 and Control Group 2 were 76.8% and 77.4%, respectively, and the median course grades were 78.8% and 76.3%, respectively, which indicates no real improvement between 2013 and 2014. Thus, the overall course grades do not suggest increased learning in the course as a result of using the higher quality lab equipment.

Perspectives of Instructors

Regardless of the difference in sophistication and quality of the desktop equipment used for the strength of materials lab experiments in 2013 and 2014, from the perspective of the instructors the students in both cohorts appreciated the opportunity to do some actual physical testing and measurements associated with the theoretical topics they were learning in lecture. This was clearly evident from the responses of the 2014 experimental groups to the surveys they completed after each lab. Even though the 2013 control groups did not complete surveys, it was evident that they appreciated the homemade lab experiments based on their reactions and behavior during the lab periods. Although the instructors were concerned that the control group students would complain about the simplicity of the homemade experiments used, not once did such a complaint arise.

In the opinion of the two instructors, both the homemade experimental set-ups and the more sophisticated, higher quality set-ups allowed students to collect meaningful data and perform calculations that verified key concepts related to the behavior of materials subjected to loading. Some advantages associated with the higher quality equipment included:

- More robust and accurate instrumentation for making deformation/displacement measurements,
- More carefully manufactured specimens resulting in computed material properties that compared better to published values, and
- More flexibility in terms of different loading and support configurations that could be evaluated for a given experiment (not used in this particular study).

These advantages can provide students with some additional satisfaction from the lab experience. In addition students seemed to respond with a little more enthusiasm to the higher quality, more sophisticated experimental set-ups from the educational equipment manufacturers.

At the same time, there were some disadvantages associated with the more sophisticated lab equipment. In some instances students found it a bit tedious to set the instrumentation up properly to get the required measurements. There were also isolated cases where problems were encountered getting clamps to hold materials or gauges sufficiently secure so they did not slip during an experiment. Some students also found using the software to collect data for the tensile testing experiment (with the tensile testing machine) a bit challenging. It is anticipated that some of these issues will diminish as the instructors become more familiar with the equipment and can provide more tips to avoid these problems.

Conclusions

This particular study has collected data to assess whether student perceptions, motivation, and learning in an undergraduate Strength of Materials course are affected by the sophistication and quality of the equipment used to conduct lab experiments. The information collected does not clearly show that the use of more sophisticated, higher quality desktop set-ups from educational equipment manufacturers causes a strong, clear improvement in student perceptions, motivation, and learning in Strength of Materials versus using homemade experimental set-ups. There was a rise in the student ratings of the two instructors for this course when the higher quality equipment was used which may indicate an improvement in student perceptions of the course as a result of using this equipment. However, there may be other factors that caused the improvement in the instructor ratings. In terms of homework and lab performance, there was only evidence of statistically significant homework improvement for one of the two experimental/control groups from whom data were collected, indicating the improvement in homework may be due to other factors. There was no consistent improvement in lab performance. Hence there does not appear to be an improvement in overall student motivation for the course as a result of using the higher quality equipment. In terms of student learning, there was only very limited statistical evidence of improvement in exam scores for one of the two experimental groups in comparison to their respective control groups. This information seems to indicate that there was not a significant improvement in student learning as a result of using the more sophisticated equipment in labs.

Despite the lack of clear improvement in student perceptions, motivation, and learning for the Strength of Materials course as a result of using higher quality, more sophisticated lab equipment, it is the opinion of the authors that investing in such equipment is worthwhile if a department's budget allows it. Using the components and instrumentation of the higher quality equipment allows students to make more accurate measurements, resulting in evaluated material properties and behaviors that are generally much closer to published values. In addition, these set-ups generally provide more flexibility in terms of the types and number of cases that can be evaluated. Students also seem to respond to the higher quality equipment with a little more enthusiasm and students who used this equipment indicated that it helped them to better understand related theoretical concepts. Overall, the authors feel that the more sophisticated, higher quality desktop equipment provides for a richer and more satisfying learning experience for students, even though it may not be directly reflected in measured student performance criteria.

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